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THESIS

NAVAL AVIATION AGING WIRING: PROGNOSTIC AND DIAGNOSTIC SOLUTIONS

by

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The Navy and Marine Corps provide key forward-presence, crisis response and war-fighting capabilities to our nation's leaders and joint commanders. Naval Aviation plays a central role in every naval mission.

Unfortunately, the tools of naval aviation's power, its aircraft, are becoming alarmingly old. The average age of the naval aviation inventory is in excess of eighteen years old. The nerve center of today's sophisticated aircraft, wiring, is also aging and in some cases aging faster than the aircraft themselves. This study was initiated to determine the state of aging aircraft wiring in naval aviation, explore emerging technological solutions to support these systems as they age, and make a recommendation for a course of action.

This thesis provides an overview of the aging wiring problem and performs an analysis of possible technological solutions. Specifically, several prognostic and diagnostic technologies exist in the field of aircraft wiring. This thesis will discuss and evaluate these technologies in terms of ramifications, implementation, costs and benefits. Simple cost and cost savings models for technology application will be formulated using data from the Navy T-45 training program and commercial airlines to make a purchase recommendation to the Naval Air Systems Command's Aging Aircraft Integrated Process Team.

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NAVAL AVIATION AGING WIRING: PROGNOSTIC AND DIAGNOSTIC SOLUTIONS

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ABSTRACT

The Navy and Marine Corps provide key forward-presence, crisis response and war-fighting capabilities to our nation's leaders and joint commanders. Naval Aviation plays a central role in every naval mission.

Unfortunately, the tools of naval aviation's power, its aircraft, are becoming alarmingly old. The average age of the naval aviation inventory is in excess of eighteen years old. The nerve center of today's sophisticated aircraft, wiring, is also aging and in some cases aging faster than the aircraft themselves. This study was initiated to determine the state of aging aircraft wiring in naval aviation, explore emerging technological solutions to support these systems as they age, and make a recommendation for a course of action.

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The author would like to acknowledge those individuals who provided their support throughout the information-gathering phase of this thesis. I would also like to thank my wife, Norma, for her patience and support during the thesis process.

I. INTRODUCTION

A. BACKGROUND

In a world in which the United States has vital interests overseas, Navy and Marine Corps forces provide key forward-presence, crisis response and war-fighting capabilities to our nation's leaders and joint commanders. Naval Aviation plays a central role in every naval mission, from establishing battlespace dominance to projecting power ashore. Naval Aviation forces - aircraft carriers and aviation-capable amphibious ships with their embarked air wings and aviation combat elements, land-based maritime patrol, support aircraft and helicopters operating from surface combatants and auxiliary ships - are the focal point of U.S. naval power.

It is with great concern that we point out that the Navy's aircraft are becoming alarmingly old. The average age of the naval aviation inventory is in excess of eighteen years and is now aging one year every year since few new aircraft are entering service. The heart of today's aircraft fleet is its wiring. Wiring is also and in some cases aging faster than the aircraft themselves. This study was initiated to determine the state of aging aircraft wiring in naval aviation, explore emerging technological solutions to support these systems as they age and make a recommendation for a course of action.

B. PURPOSE

This thesis provides naval aviation planners with current information regarding the state of prognostic and diagnostic technologies in the field of aircraft wiring. A cost analysis of existing prognostic and diagnostic concepts will be performed and a recommendation made for the purchase or non-purchase of available technologies.

C. SCOPE

This study will include: (1) an analysis of the aging aircraft and aging wiring problem in Naval Aviation, (2) a review of current operational tempo and requirements, (3) an analysis of some current wiring prognostic and diagnostic technologies, (4) a discussion of the costs and benefits of adopting various emerging prognostic and diagnostic technology for today's aging systems.

D. METHODOLOGY

The methodology used in researching this thesis consisted of on-site interviews and correspondence with representatives of Naval Air Systems Command (NAVAIR), Defense Advanced Research Projects Agency (DARPA), Delta Airlines, United Airlines, the Joint Strike Fighter (JSF) Program and private industry; various briefs; websites; CD-Rom systems and professional papers. A brief review was conducted of current operational tempo and conditions. Possible applications for current prognostic and diagnostic systems to aging aircraft wiring systems were researched as well as costs versus benefits.

E. ORGANIZATION

The reader now has been provided with the background, purpose, scope and methodology for this thesis. The following chapters will flow as described in regards to the scope and methodology. The study will be organized into the format depicted below.

I. Introduction

II. The Aging Aircraft Problem

III. Prognostic and Diagnostic Technologies

IV. Costs and Benefits

V. Conclusions And Recommendations

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II. THE AGING AIRCRAFT PROBLEM

A. INTRODUCTION

The Navy currently operates over 2,100 aircraft that are over fifteen years old, 965 of which are more than twenty-five years old.[1] Figure 1 displays the aging trend for the aircraft fleet.

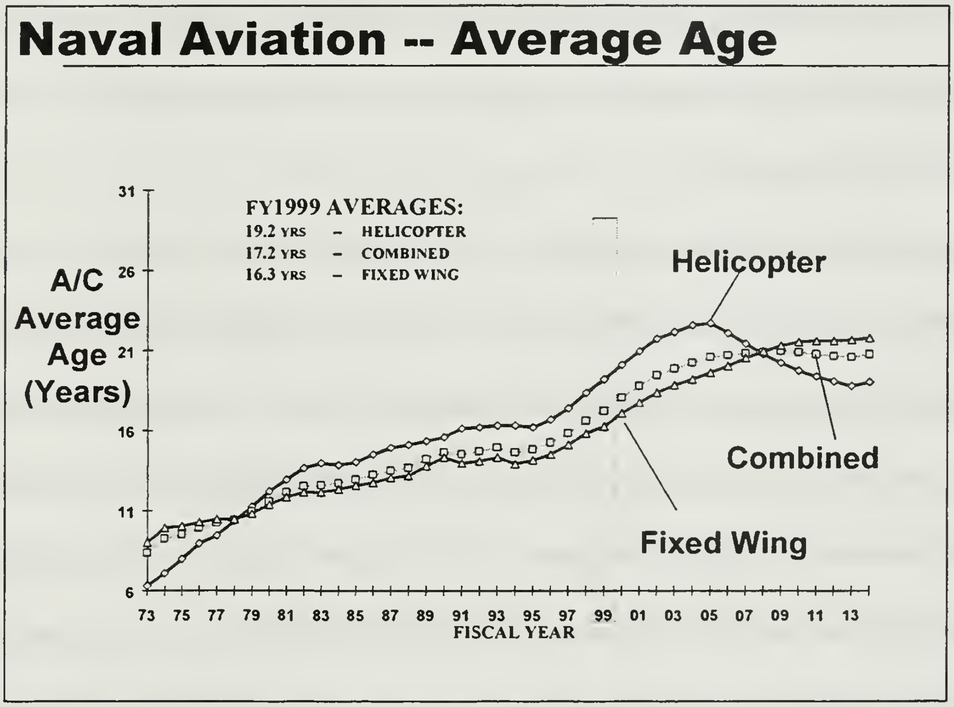

Figure 1 Aircraft Average Age Trend From: Massenburg, 2000

Some aircraft such as the CH-53D and CH-46 are over 25 to 30 years old.

[1] See statement of the Honorable Richard Healing, Office of the Assistant Secretary of the Navy Director, Navy Safety and Survivability before the House Transportation and Infrastructure Subcommittee on Oversight, Investigations, and Emergency Management Hearing on Aircraft Electrical System Safety, 5 October 2000.

With this old age come higher support costs in maintenance and manpower. Some aircraft have replacements on the way, such as the F/A-18 E/F Super Hornet for the F-14 Tomcat and older F/A-18 C/D Hornets; the Boeing 737 for the C-9; the V-22 for the Marine Corps H-53 and H-46; and the CH-60 for the Navy's H-46. Howeve ral platforms do not have replacements currently planned. The EA-6B Prowler, S Viking, E-2C Hawkeye and the P-3 Orion do not have replacements on the hori Limiting or controlling aging impacts is critical for future mission accomplishme Even the platforms with replacements coming will be operational for several years iew systems come into service.

The Air Force faces a similar problem. The Air Force Chief of Staff, General Michael E. Ryan, claims that even if all modernization programs now planned are executed, the average age of the service's aircraft will reach 30 years old in 2019.[2]

Even the airline industry is facing an aircraft age problem. Of the current domestic passenger fleet, 40% of the aircraft have been in service for more than 20 years. Since 1983, the National Transportation Safety Board (NTSB) has investigated at least two-dozen incidents, including four with fatalities, in which aging wiring was cited as a factor.[3]

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[2] Mann, Paul, "Geriatric Ward," Aviation Week & Space Technology November 2000; 29.

[3] House Subcommittee on Oversight, Investigations, and Emergency Management Hearing on Aircraft Electrical System Safety, 5 October 2000.

The new Chief of Naval Operations, Admiral Vern Clark, stated in recent Congressional Hearings that the Navy is short by $17 billion annually and its "aviation force is now the oldest it has ever been in history …Our cost models do not accurately predict the true cost of operating our aviation assets… Until we have achieved a modernized force, we will continue to face the challenge of climbing maintenance expenses."[4]

The age of fleet aircraft coupled with limited new procurements require significant maintenance/support levels and increased funding to maintain acceptable readiness levels. The lack of ability to move funds/reinvest savings and overall inadequate operations and maintenance, Navy (O&M, N) funding keep aircraft programs from finding cost effective solutions. Life-cycle ownership costs growth needs to be contained to enable modernization. This must be coupled with innovations in acquisition and cycle time to field new systems. Strides have been taken to speed-up the acquisition cycle but much improvement is still needed. Not only does aging aircraft promote higher support costs and decrease readiness, but also reduces quality of life for fleet operators and maintainers.

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[4] Mann, Paul, "Bush, Gore Promises Fall Short Of Desired Military Spending," Aviation Week&SpaceTechnology 2 October 2000; 34-36.

B. ENVIRONMENT

Naval aviation performs its missions in various environments. Temperature extremes, salt water, impacts/vibration and stress are the norm in air operations. First, an Air Wing may deploy in the winter and operate in the cold over Bosnia or Kosovo and a month later is in the heat of the Persian Gulf. Second, that Air Wing may then transit through the Adriatic or Mediterranean and fly cold-weather operations, again all in the span of a six-month deployment. These extremes extract a toll on today's systems.

C. OPERATIONAL TEMPO

In 1999 over 22 major naval operations were sustained, including Southern Watch over Iraq. Over 71 naval exercises were accomplished with over 57 different countries.[5] At any one time up to six aircraft carriers and their respective Air Wings may be underway. These underway periods may range from overseas deployments to deployment work-ups to initial interoperability operations at the beginning of the inter-deployment training cycle.

As Figure 2 shows, the readiness of our Carrier Air Wings has dropped significantly in the past five fiscal years, especially during the critical training period of the inter-deployment cycle.

[5] Rear Admiral W.B. Massenburg, USN. "Maintaining Yesterday's Weapons for Tomorrow's Warfighter," US Naval Air Systems Command 2000.

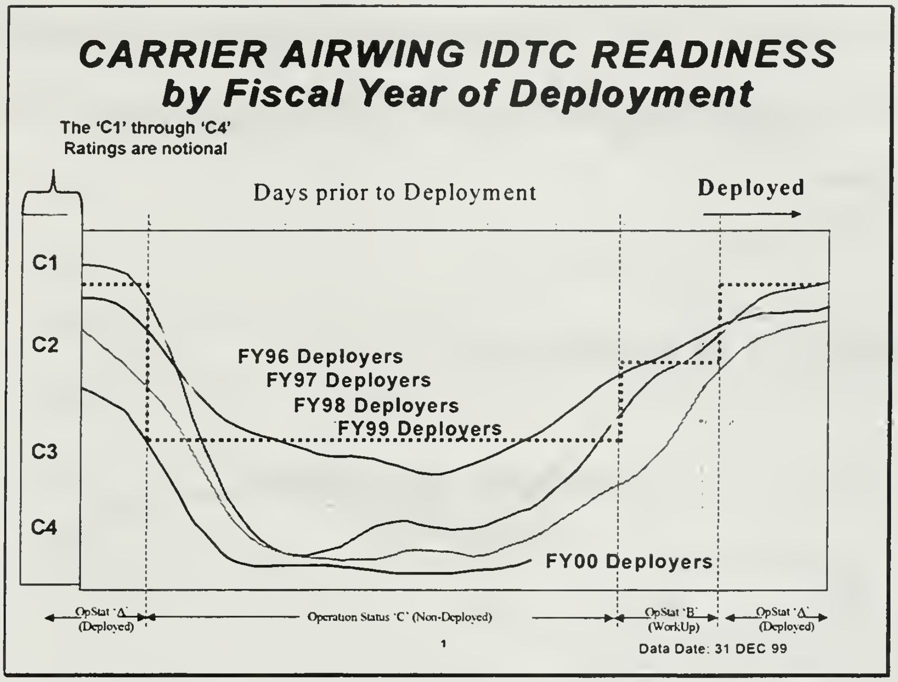

Figure 2 IDTC Readiness From: Massenburg, 2000

The operational tempo has been very high, but the number of assets (ships and planes) has shrunk and the remaining aircraft assets are aging rapidly. Little to no thought was ever given to age limitations because most designers felt aircraft and related systems would be replaced before age became an issue. Even aircraft that are relatively young are being stressed to their limits. The F-18 community is expecting to spend $878 million over the next 12 years to conduct a service life extension (SLEP) program for 355 F/A-18 C/D aircraft. However, only enough funding has been identified to put 57 jets through during the next seven years. We conclude the SLEP's are necessary because the integrity of the aircraft is being worn down ahead of schedule due to unanticipated high operational tempos.[6] Overall naval aviation readiness trends are falling as Fi[illegible] 3 illustrates, and maintenance man-hours per flight hour are increasing as Figure 4 demonstrates.

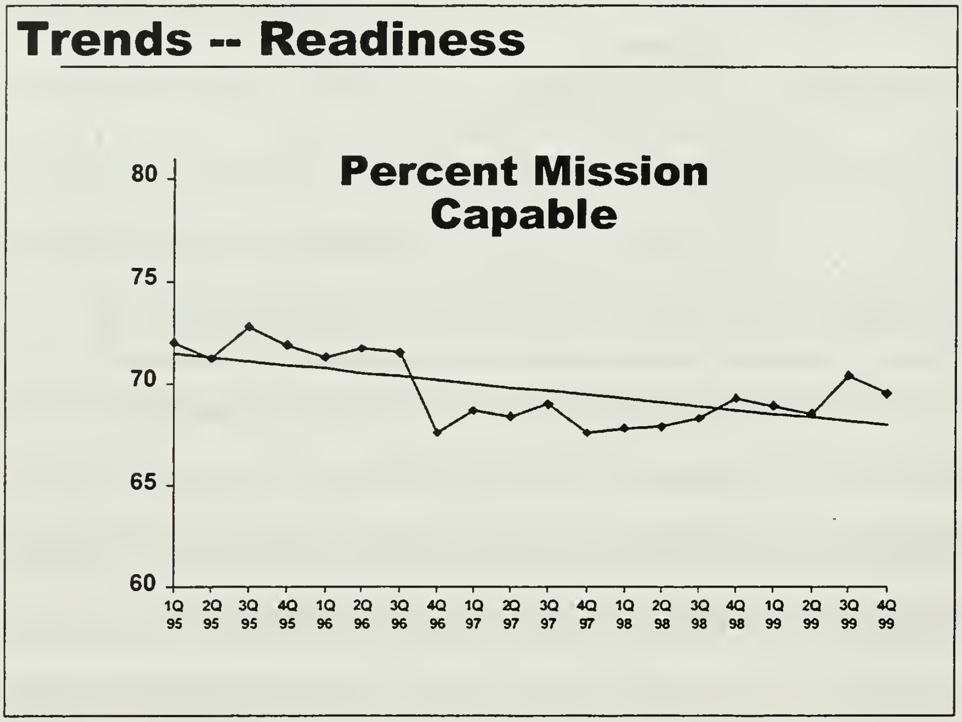

Figure 3 Readiness Trend From: Massenburg, 2000

[6] Brown, David. "High op tempo stings Hornets-Pace of carrier takeoffs, landings takes a toll on C and D models, "Navy Times 18 September 2000. 14.

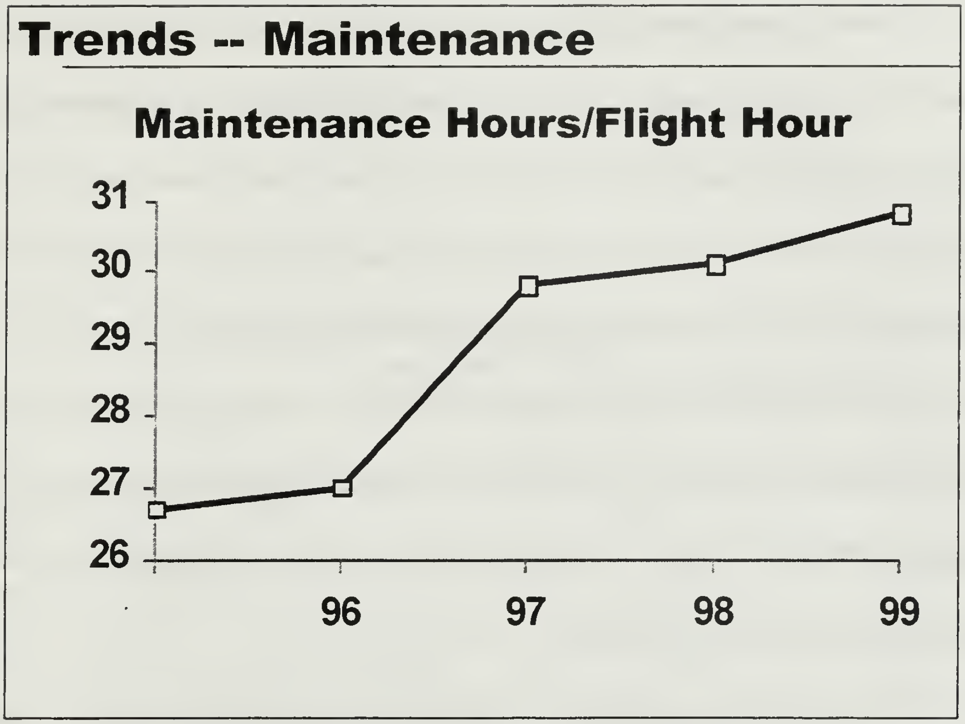

Figure 4 Maintenance Man Hour Trend From: Massenburg, 2000

In order to stop the skyrocketing cost of maintaining older aircraft, while supporting current operational tempo, new and more effective ways to do maintenance must be found. Effective Prognostic Health Management (PHM) systems and diagnostic systems could streamline maintenance operations. PHM systems are devices and sensors installed in aircraft that indicate when a component is going to fail before it does so. Effective PHM would enable decision makers to optimally schedule more preventive maintenance vice costly, reactive unscheduled maintenance. Effective diagnostic systems could improve fault detection, location, repair and verification of repair while shortening the time it takes to accomplish all these tasks.

The Navy, Air Force, Federal Aviation Administration (FAA), NASA and private industry are attempting jointly to insert technology and improve maintenance/support actions to address the aging aircraft dilemma. Various organizational and joint programs such as the White House Office of Science and Technology Policy's (OS&TP) Wire System Safety Interagency Working Group (WSSIWG), NAVAIR's Aging Aircraft IPT, the Aircraft Wiring and Inert Gas Generator (AWIGG) working group, and the Naval Air Vehicle Wiring Action Group (NAVWAG) have been formed. These groups demonstrate the seriousness of the aging problem and the coordinated support of government, industry and academia.

Various technologies have been developed that have the potential to improve the safety of America's aircraft fleet, provided the requisite resources are made available to assess their feasibility.

D. WIRING

Aircraft wiring has evolved from a nice-to-have item to the very lifeline of modern aircraft. Today's aircraft can have up to several hundred miles worth of wiring aboard. Flight controls, avionics, power plants, communications, weapon systems, environmental and monitoring systems are all powered, interconnected and controlled by wiring. One to two million man-hours per year are spent troubleshooting and repairing wiring. Approximately 147,674 non-mission capable (NMC) hours per year and 1,077 mission aborts are attributed to wiring problems. Between July 1995 and December

1997 there were 64 in-flight electrical fires.[7] Figure 5 illustrates wiring failure trends for current, front-line, fixed-wing platforms.

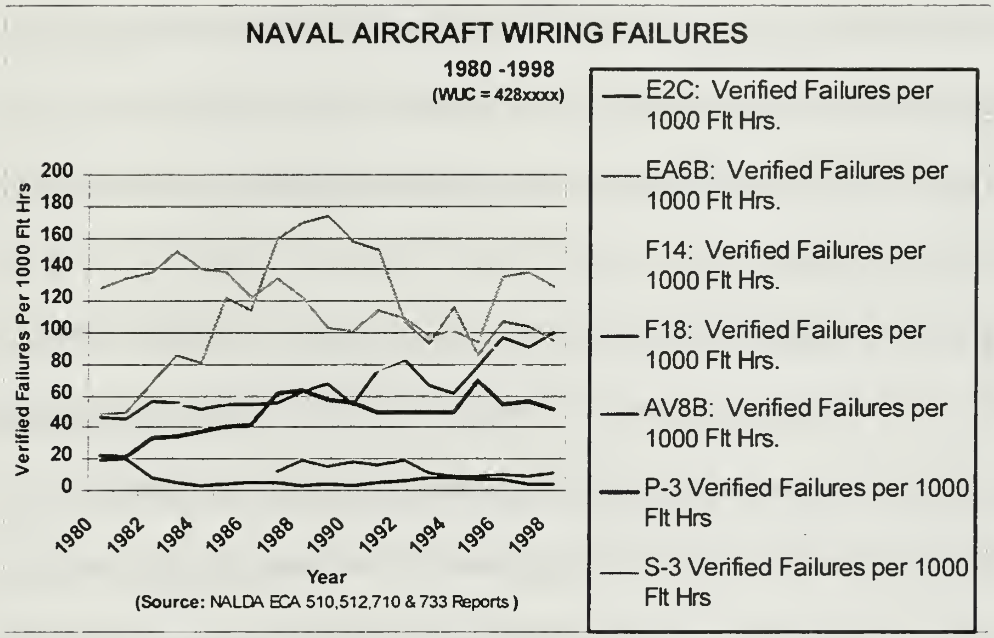

Figure 5 Aircraft Wiring Failures From: NAVAIR 4.4.4, 2000

A significant amount of wiring on an aircraft may be inaccessible for inspection. As aircraft age so does the wiring. In some cases the wiring ages faster than the airframe due to its physical and chemical characteristics. Intrusive maintenance inspections of wiring or other systems in close proximity lead to twisting, bending, pinching and general trauma to aircraft wiring bundles and cause insulation abrasion during in-flight vibration.

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[7]Sean A. Field, Naval Air Systems Command. e-mail to the author, 17 November 2000.

Spilled and leaked fluids, such as hydraulic fluid and salt water can eat wiring insulation. Wire bundles also stretch and settle with age, and react with moisture and humidity. This leads to polymer chain scission and loss of inherent mechanical and dialectic strength in widely used polymide wire. Couple the complexities of wiring installations with the harsh environment of Naval Aviation and the now banned polyimide wiring, still in 51% of aircraft, and the Navy faces a very serious problem. Wiring failure can cause shock hazards, electrical fires, loss of flight critical equipment, explosions, and damage or loss of assets or personnel.

Polyimide insulated wire insulation was widely installed on aircraft in the 1970's and early 1980's. This material was first thought to be ideal for aircraft wiring insulation because of its light weight, thinness and high thermal stability. The problem, as was found out later after installation in several platforms, is that it ages quickly in moist environments, becomes brittle and prone to cracking. It is full of carbon that enables arc tracking. Initially what happens is that moisture damaged polyimide insulation allows tiny arcs to develop. These arcs don't trip circuit breakers or interrupt operation of the respective systems, but it breaks down and carbonizes the insulation. This Carbon conducts electricity and arc tracking occurs which can be explosive. Arc tracking in an explosive environment could be catastrophic. This is what is believed to have happened in the loss of TWA 800 in July 1996 and Swissair flight 111 in September 1998. Aging wire is also recognized as the cause of a cargo door separating from a United Airlines flight in which nine people were killed. Polyimide insulation was phased out in 1980's in production and repair of naval aircraft. The Navy also started a program to remove polyimide wiring from critical areas and developed fire control systems to handle areas where wiring could not be removed economically. The removal of polyimide insulated wiring completely from the naval aircraft inventory would be too costly, manpower and out-of-service time prohibitive.

National Transportation Safety Board (NTSB) investigation of wiring on TWA 800 and inspections of older aircraft have led to findings that a need exists for (1) improved maintenance practices, (2) better training for maintenance personnel and FAA inspectors, and (3) new technologies for detecting and preventing problems with aircraft wiring.[8]

In light of the TWA 800 and Swissair disasters, the FAA, as a member of the Aging Systems Task Force (ASTF) with airlines and aircraft manufacturers did a non-intrusive inspection that looked at 70 aircraft of eight different models. The inspection was purely visual inspections that could detect only physically observable faults. On average, four to five discrepancies were found per aircraft type. Discrepancies were found on multiple aircraft within a type so the average per individual aircraft was higher.

However, this inspection was done the same way most programmed wiring inspections are done, visually. Even the best technician can't detect microscopic cracks in wiring insulation that could become a concern.

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[8]See Statement of Alexis M. Stefani, Assistant Inspector General for Auditing, U.S. Department of Transportation before the House Transportation and Infrastructure Subcommittee on Oversight, Investigations, and Emergency Management Hearing on Electrical System Safety, 5 October 2000.

A recent inspection of Navy P-3 aircraft indicated 25% of wire discrepancies were found. Other inspections completed by Navy wiring inspectors have indicated up to 75% of all discrepancies can be detected visually. However, it doesn't matter what the exact amounts of defects are observable visually since a great deal of wiring is unobservable due to where it is installed and lack of access. Useful non-destructive tools must be made available to accurately detect defaults and gather useful information.[9]

Nomenclature	Support$	DMMH	NMCM	NMCS	PMCM
MAINTENANCE INSPECTIONS					
EA-6B	$49,769,753	710,780	247,561	704	0
F/A-18	$99,781,092	1,428,159	820,787	1,037	25
H-60	$50,548,352	724,328	329,022	276	0

Table 1 INSPECTION COSTS From: Katzberg, 2000

We must work smarter not harder in our inspection process. Inspections comprise the biggest percentage of cost for fleet maintenance.[10] Table 1 displays the key indicators of inspection support costs, Direct Maintenance Man Hours (DMMH), Non-Mission Capable Maintenance (NMCM) hours, Non-Mission Capable Supply (NMCS) hours and

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[9] Ed Taylor, Jim Shaw and Bob Ernst, Correlation of Environment and Age Effects on Aircraft Wiring, 22 September 1999.

[10] Bob Katzberg, Naval Air Systems Command 2000.

Partial-Mission Capable Maintenance (PMCM) hours for the EA-6B, F/A-18 and H-60 (HS & HSL) communities for the period December 1998 to May 2000.

Another major problem is the lack of accurate wiring discrepancy data collection. Current reporting systems, military and commercial, are not geared toward reporting problems with wiring. Aging wire discrepancy trend analysis is inadequate because most wiring faults are not recorded as "wiring gripes" but as discrepancies to the parent system. For example, an aircraft may have had serious wiring problems between a power supply and sensors/displays of the navigational system but for recording purposes the fault detection and repair is documented under the navigation system and not wiring. A traceable sub-classification, which assists in trend analysis or hazard identification, and greater training/re-education of documenting wiring gripes is needed to help decision-makers, program managers and engineers really know how the aging wiring is performing.

Wiring troubleshooting is very manpower intensive and time consuming. The primary troubleshooting method is still a technician with a voltmeter and a flashlight. Advances in avionics systems, such as Built-In-Test (BIT) have hampered or even misled technicians if faults turn out to be in system wiring.

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III. PROGNOSTIC AND DIAGNOSTIC TECHNOLOGIES

A. PROGNOSTIC HEALTH MANAGEMENT (PHM)

Prognostic Health Management (PHM) is as concept whereby technology such as sensors, are imbedded in a system that provides the operator and maintainer critical information. This information would include current malfunctions and most importantly indications of future failure or malfunctions.

The Joint Strike Fighter (JSF) program defines on-aircraft PHM as a combination of Micro Electro-Mechanical System (MEMS) and Micro-Electro-Optical Systems (MEOS) with prognostic microprocessors to sense, detect, consider, prognoses, message and perhaps correct problems.[11]

The JSF program's goal is PHM that enables their logistics system. This system enables PHM and other system status units to transmit health and status information to support sites via data links. The goal is to eliminate ground support test equipment by moving test and diagnostic systems onboard the aircraft to detect, diagnose and isolate failures. JSF believes onboard PHM systems would be more effective in reducing "cannot duplicate" test results that occur often with ground-based (non-flight troubleshooting tests.) The Autonomous Logistics system even enables these onboard

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[11] Blemel, Kenneth G.; Dynamic Autonomous Test Systems for Prognostic Health Management, Joint Strike Fighter Program Office, Arlington, VA. 1998.

systems to order parts, through the Joint Distributed Information System (JDIS) network, and initiate maintenance action requests during the course of a flight.

Condition Based Maintenance (CBM) is the use of detection devices to monitor system and subsystem components status and combine this status with computer algorithms to calculate reliable estimates of "remaining useful life." This enables real-time decisions to be made that shorten or extend time between overhaul or replacement. This would replace the current system of overhaul or replacement at a given number of hours, landings, days, starts, etc. Therefore, a replacement or overhaul decision is based on actual type of usage. Various automobile manufacturers use this concept. The Navy rotary-wing community is implementing CBM for various systems, especially for vibration analysis. JSF would like to combine PHM with CBM through autonomous logistics to eliminate scheduled maintenance.

After discussions with engineers at the Defense Advanced Research Projects Agency (DARPA) that work on the JSF program, it is clear that onboard PHM is a viable concept. However, it is recognized as feasible and being adopted for structural members, powerplants and select avionics, but not for wiring.[12]

B. SMART WIRE

The Naval Air Systems Command (NAVAIR) is working on a concept called "Smart Wire." Their definition of Smart Wire is embedded intelligence and sensors in

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[12] Interview with William J. Scheuren, Leo Fila, Kimberly Becker, 8 August 2000.

the wiring system to manage the health of wiring. This is basically as close to true PHM the Navy can get for existing legacy systems. Smart Wire is intended to be a tool to provide diagnostic and prognostic capabilities plus document the current condition of an aircraft wiring system on a Bureau Number (BuNo) basis. This “health” tracking system is intended to provide the capability to be proactive in fixing wire failures by addressing them during planned maintenance.

Smart Wire would also be managed similarly to a component such as an engine or Line Replacement Units (LRU). This could target certain aircraft for future upgrades or overhaul based on traceable data.

The Smart Wire program will also make the effort to work with other programs such as the Naval Sea Systems Command’s (NAVSEA) DDG-51, DD21, CVX and NSSN programs, as well as other government agencies such as the FAA, USAF, NASA, Army and Department of Energy: and other entities such as commercial airlines, automotive industry, nuclear power plants, and other industrial applications.[13]

C. ARC FAULT CIRCUIT BREAKER (AFCB)

Power wiring is protected by circuit breakers that detect continuous short circuits and overloads. However, arcing faults (discussed in chapter two) with their intermittent nature and lower peak currents characteristics are not detected by current conventional circuit breakers. NAVAIR, the FAA, and the Office of Naval Research (ONR) have a joint program to develop arc fault circuit breakers for aircraft use.

Arc fault detecting circuit breakers are currently available commercia[illegible]r residential and commercial use. This existing technology is a strong candidate [illegible]apid development and application to aviation.

Arc faults are intermittent short circuits, which draw far less current than the traditional bolted short circuit in addition to lacking the duration of an overloaded circuit. Arc faults will not trip the conventional circuit breakers because of their low current, and short duration nature.

Current visual inspection methods are the primary means to detect degradations in installed wiring. Due to the inherent limitations of visual inspection oversights and lack of access to some wiring, other inspection techniques should be developed. However, all inspections are periodic in nature and therefore do not provide constant coverage. Arc fault circuit breaker technology is not a substitute for preventive, programmed maintenance, but it provides protection against arc faults.

Arc fault circuit breakers not only sense arcing faults, but also have the thermal trip capabilities of current conventional circuit breakers. Arc faults are an issue in home use as well. In 2002, the National Electric Code will require arc fault circuit breakers in new home construction.[14] The home environment is very docile compared with naval aircraft use and operating environments. However, as of late most homes and naval aircraft share a common thread: old age.

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[13] Sean A. Field, Naval Air Systems Command. e-mail to the author, 17 November 2000.

[14] Singer, Charles, Pappas, Robert; Arc Fault Detecting Circuit Breaker for Aging Commercial and Military Transport Aircraft, Naval Air Systems Command, Federal Aviation Administration, 2000.

Of course a home use arc fault circuit breaker cannot be simply installed on an aircraft. The arc fault circuitry must be changed. The size of current arc fault circuit breakers must also be reduced by at least 50%.

Safety is the number one priority of introducing arc fault circuit breakers but other benefits could include troubleshooting and repair time reduction, cost reduction and promotion of further innovation.

Arcing is only one symptom of aging wiring. However, arc fault circuit breakers can effectively reduce the risk of arcing and its subsequent damage. Arc fault circuit breakers must be affordable and easily retrofittable into the existing fleet.

According to the NAVAIR Aging Aircraft Integrated Process Team (IPT), arc fault circuit breakers could reduce wiring maintenance time by 30 percent, reduce in-flight fires by 80 percent and provide an annual savings of $12 million. At this time introduction is tentatively scheduled for fiscal year 2005. Boeing is also working on AFCB technology and plans limited production in 2001 and a "full family" of arc fault circuit breakers by 2002.[15]

D. DIAGNOSTICS

Diagnostics differs from prognostics in that it is more testing in nature and an identification of a fault by examination or analysis where prognostic is more of a prediction of future fault. Investment in diagnostic technology is a very feasible option at

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[15] See Statement of Alexis M. Stefani, Assistant Inspector General for Auditing, U.S. Department of Transportation before the House Transportation and Infrastructure Subcommittee on Oversight, Investigations, and Emergency Management Hearing on Electrical System Safety, 5 October 2000.

this time. It is also less intrusive and viable for legacy systems. Utilizing and investing in more efficient diagnostic systems place the proper tools in the hands of those who need them: fleet maintainers. More effective diagnostic systems can assist technicians and maintenance decision-makers in maintaining the aging systems that exist today.

The Department of Defense (DOD), Federal Aviation Administration (FAA), NASA, airline, corporate and general aviation communities are all looking for better diagnostic systems to maintain aging aircraft including through joint programs. Techniques to find defects in cables such as coaxial cable are relatively mature, using Time Domain Reflectometry (TDR) and Standing Wave Reclectometry (SWR). There have been past efforts to expand these techniques to other types of wire and cabling, but not any industry-wide reason to do so. However, recent attention and concern for aging aircraft systems has caused a greater effort toward degradation-detection in aviation wiring systems.

NASA has one of the ultimate aging aerospace vehicles, the Space Shuttle. The shuttle wiring system is highly complex, subject to wearing extremes and age. It is very difficult to prosecute wiring problems on the Shuttle. Decreased confidence in Shuttle wiring integrity leads to a great deal of manual inspection and troubleshooting, which in turn leads to increased down time. NASA has recognized that any technology that identifies a future fault or localizes an existing one accurately, could lead to significant cost savings in time and labor. It is believed the cost of deploying such technology is justified by increased safety.[16]

One of the emerging technological innovations becoming available is a hand-held Standing Wave Reclectometer (SWR), being developed and distributed by Eclypse International Corporation of Corona, California. Eclypse's SWR is based on a prototype design and patent by NASA at the Kennedy Space Center, Florida. The SWR (pictured below) was developed to provide a portable, reliable device to verify the condition of electrical power and signal distribution systems. Eclypse International has exclusive rights to the patent for SWR.

Figure 6 Standing Wave Reflectometer

[16] NASA Ames Research Center, Wiring Integrity Research (WIRe) Pilot Study, 25 August 2000.

The SWR is best described as an Impedance Based Cable Tester. Impedance measure of the total opposition to current flow in a circuit. The SWR is attached only one end of a conductor. It sends a spectrum of frequenc[illegible]wn the conductor, and depends on a reflection of a portion of the signal from fea[illegible] the conductor, which result in a change in impedance. By examining the freque[illegible] frequencies at which a standing wave occurs, the fault feature can be located.[17]

The Eclypse SWR is a hand-hand, battery-powered tester with a range of 1,000 feet and short or open circuit detection accuracy of 0.2 percent, which equates to mere centimeters. The SWR has a alphanumeric display, keypad, rechargeable battery with a 8-hour operating life, auto shut-off, illuminated display and keypad, serial data port, drip/splash proof and shock resistant case and an operating range of –20 to +60 degrees Celsius. It is menu driven and has ten programmable settings for various conductor types. [18]

A typical problem NASA has found in its current conventional troubleshooting environment is that troubleshooting personnel often have to disconnect several cables to ensure they are not a source of a problem. These cables are often wire bundles and difficult to access. When the wire bundle is disconnected, all systems with a wire passing through the bundle must be retested when reconnected. This validation process takes a great deal of time and manpower on systems unrelated to the discrepancy. The SWR cuts

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[17] NASA Ames Research Center, Wiring Integrity Research (WIRe) Pilot Study, 25 August 2000.

this process by being non-intrusive and highly accurate in fault detection. The SWR also cuts the time to validate the repair of the faulty system.

The overall benefits of SWR are reduced time and effort to troubleshoot, repair and validate repairs; enable proactive maintenance and most of all, lower total operating cost.

An advantage of SWR for the military is the architecture of wiring in most aircraft. U.S. military aircraft facilitate troubleshooting as most wiring harnesses feature connectors. Unlike the military, commercial aircraft do not feature as many disconnects. The prevalent practice in the commercial community is wire splices. Wire splices if done well can be as reliable as connectors and save weight. However, once spliced, wires are not as readily accessible for testing. Splicing also causes more differences in configurations form aircraft to aircraft even of the same type.[19]

Another technique for non-intrusively troubleshooting wiring and checking continuity is Time Domain Reflectometry (TDR). In TDR, a pulse is sent down the conductor. Anything along that conductor that changes impedance (changes in resistance, capacitance or inductance) will reflect some energy back along the conductor. However, the changes seen depend on sensitivity of the TDR instrument, careful measurements and interpretation of data. NASA found that TDR is not feasible for

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[18] NASA Commercial Technology Team, "NASA Success Story," online posting, 16 November 2000, <http://technology.nasa.gov/scripts/nls_ax.dll/w3SuccItem(2047).

[19] Huey, Erik C., "Military Approach to Electrical Fault Detection Going Commercial", Air Safety Week, 16 February 1998. 4-5.

detecting cable faults in the Space Shuttle. They found that faults a few meters or less from the injection point of TDR are not detected due to the extremely short travel time (e.g. a few nanoseconds) of the TDR high frequency pulse.[20]

The SWR tester can provide the distance to and accurate nature of a discontinuity in an electrical cable, without removal of the cable from the circuitry to which it is connected. The SWR's simple design results in a tester less expensive to manufacture than a typical TDR device. The SWR tester also promotes efficient utility with its portability, selectable frequency range and automatic operation.[21]

SWR is recognized as a means of localizing and identifying hard faults. However, it is not currently able to locate defects in wiring insulation, but the technology could be adapted to do so.[22] The ultimate technology could find hard faults as it does now, diagnose the health of wiring insulation and prognosticate the remaining lifetime of wiring insulation. Companies such as Boeing believe a different application of the technology used in SWR can be used to find insulation degradation with broad band impedance spectroscopy.[23]

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[20] NASA Ames Research Center, Wiring Integrity Research (WIRe) Pilot Study, 25 August 2000.

[21] US Patent & Trademark Office, "Non-intrusive Impedance-based Cable Tester," online posting, 2 November 1999, <http://164.195.10011/>

[22] NASA Ames Research Center, Wiring Integrity Research (WIRe) Pilot Study, 25 August 2000.

[23] Rogovin, Daniel, Mitchell, Ed, Fourth Joint DoD/FAA/NASA Conference on Aging Aircraft, May 15-18, 2000: Wiring Insulation Health Monitoring Via Impedance Spectroscopy St. Louis, Missouri, 2000.

IV. COSTS AND BENEFITS

A. INTRODUCTION

Unfortunately, in today's budget environment DOD cannot afford to pursue every concept to battle aging aircraft wiring systems. The primary concepts discussed in this thesis include Prognostic Health Management (PHM), Arc Fault Circuit Breaker (AFCB), Smart Wire and the Standing Wave Reflectometer (SWR). This chapter will analyze some costs and benefits using basic examples.

B. STANDING WAVE REFLECTOMETRY

To analyze the SWR system a generic scenario should be established. This scenario involves an average prosecution of a wiring fault. A two-hour timeframe is assumed as the average length to prosecute a wiring fault including set-up, troubleshooting, repair and validation of the repair. Figure 7 displays the segment breakdown of the two-hour period. Wiring faults can take anywhere from minutes to several days to repair, but for this example a two-hour average will be used.

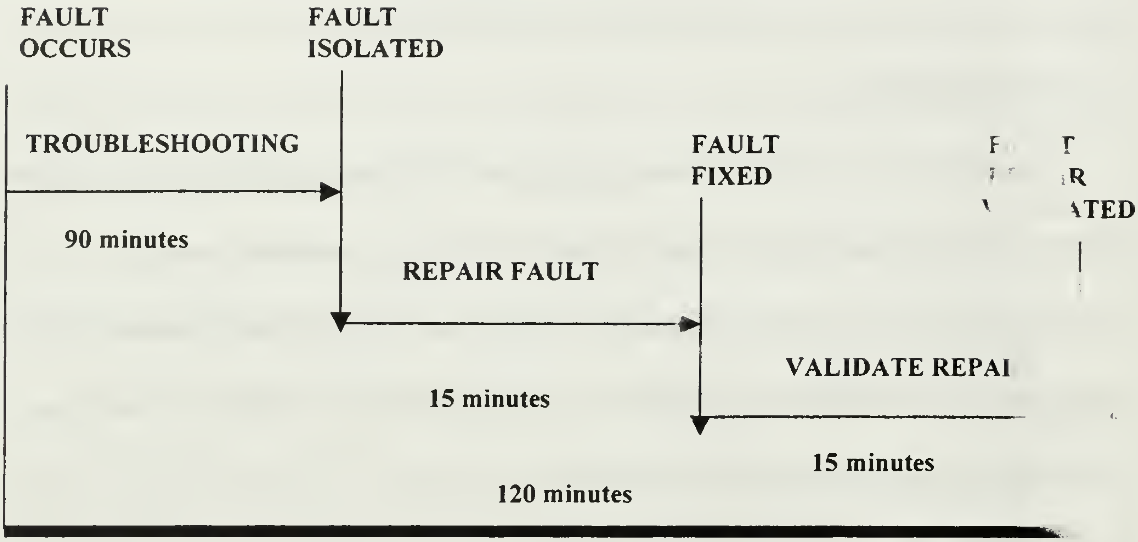

Figure 7 Current Wiring Fault Prosecution

The wiring related faults data utilized is from the Navy T-45 community. Appendix (A) displays all T-45 wiring related faults per system as well as the Non-Mission Capable hours and Non-Mission Capable Maintenance Unscheduled (NMCMU) time in hours. The total NMCMU time of 8,443.4 hours is the primary concern and the figure used for our computations. The period covered is 01 June 1999 to 30 June 2000, and the data is for an average fleet of 102 aircraft in that period. The number of technicians used per prosecution of a fault is two. The cost per hour, per technician is $35.00. Since the T-45 program uses contract maintenance personnel, exact cost per hour, per technician can be ascertained. Unfortunately, applying this model to fleet technicians could be much more difficult. During the research for this thesis, estimated organizational labor rates for fleet personnel ranged from $18 to $70 per hour were found. The exact figure has not been determined at this time.

Figure 7 displayed the breakdown for troubleshooting (including set-up), repair and validation of repair in a two-hour wiring fault prosecution. Figure 8 below displays what the new timeline could be if SWR technology is utilized. The SWR technology focuses on the time-consuming troubleshooting segment and the validation of repair.

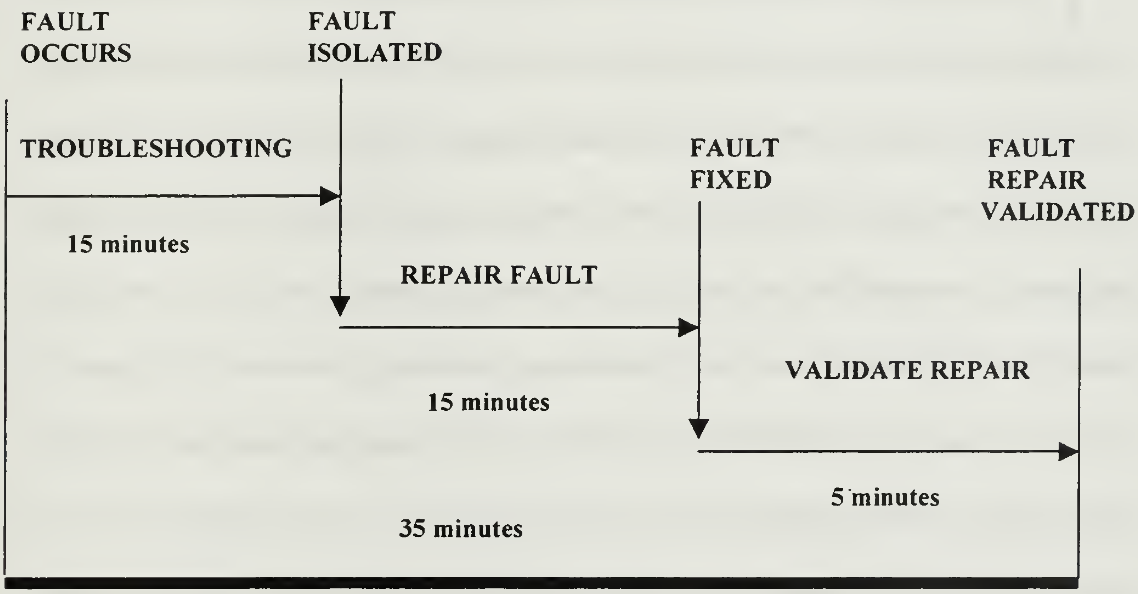

Figure 8 SWR Wiring Fault Prosecution

The time decrease using SWR is 120 minutes (2 hours) to 35 minutes. This represents a 71% reduction in time. By reducing 8,443.4 NMCMU hours by 71%, the result is 2,448.6 hours. The original labor cost was $591,038 (8,443.4 hours x 2 technicians x $35 per hour). The new labor cost with SWR is $171,402 (2,448.6 hours x 2 technicians x $35). The labor cost savings this could mean to the T-45 community is approximately $420,000 per year.

Some factors should be mentioned here: 1) not all wiring faults are te wiring faults but to the parent system as mentioned previously and; 2) the i a jet but also a basic trainer, and as such, less complex than a fleet aircraft like the F/A-18.

Appendices (B) and (C) display comparable wiring fault data for the F/A-18 EA-6B communities such as Direct Maintenance Man-Hours (DMMH), Non-Mission Capable Maintenance (NMCM), Non-Mission Capable Supply (NMCS), Partial Miss Capable Maintenance (PMCM) and Partial Mission Capable Supply (PMCS) in hours the period December 1998 to May 2000. The average number of tec... to prose these wiring faults and the per hour labor rate are not known. However, ng a reduction to the total of NMCM hours for the F/A-18 community leads to a tion from 79,222 to 22,974 NMCM hours in an 18-month period. Another way to express the time saved is if the T-45 model of two maintenance personnel at $35 per hour is applied to the F/A-18 example. A savings of $3,937,360 ((79,222 x 35 x 2)-(22,974 x 35 x 2)) would be realized. The EA-6B community reduction of 71% equates to a reduction from 51,048 to 14,804 hours in an 18-month period. Using the T-45 model, this realizes a savings of $2,537,080 ((51,048 x 35 x 2)-(14,804 x 35 x 2)). The bottom line however, is that with less "down" time for maintenance means more aircraft availability for flight time and training.

An important factor that should be mentioned for the F/A-18 and EA-6B example as in the T-45 one: not all wiring faults are reported as wiring faults but to the parent system as mentioned previously.

The maintenance time savings of SWR would be realized at all three levels of maintenance. A major problem with the current prosecution of wiring faults is misdiagnosis. Items such as Aviation Depot Level Repairables (AVDLR) and other system components are often misdiagnosed as the problem when often it is a wiring failure. These components are often sent to the intermediate maintenance level or even depot level for repair when there is nothing wrong with them. SWR provides a means for accurate diagnosis. It is beyond the scope of this thesis, but time savings would be realized at not only the organizational level but all three levels of maintenance.

A secondary effect of accurate diagnosis is accurate demand data on the supply system. If good components are being pulled from aircraft, demand for replacement parts are being made on the supply system. Accurate diagnosis would help eliminate unnecessary supply demands on an already stressed supply system.

Another un-quantifiable item for fleet aircraft, like the labor note previously discussed, is how much it costs the Navy when an aircraft is Non-Mission Capable (NMC) by the fact of not being available. The training aircraft community cannot quantify this loss of availability either even with their strict training syllabus. Too many factors would be involved to quantify based on aircraft type, missed aircrew training, type of mission missed, and ability to make-up or divert missions to other assets. However, one aviation community, the airlines, can accurately identify what a Non-Mission Capable aircraft means to them. Aircraft in the airline industry are revenue producers, and as such have direct quantifiable cost associated when unavailable. Based on information from major airlines, some dollar figures can be applied to the T-45 model. A figure from one major airline is $59,000 as the dollar amount associated with an unavailable aircraft per day with an average daily utilization rate of 8.7 hours. Other airline figures are similar. Since some passengers and cargo can be diverted to other aircraft, a figure of $40,000 is used for cost analysis by Delta Air Lines.[24] Military missions could also be subjected to schedule flexibility, but perhaps not as much as in the airline community. For example, one airline could divert cargo and passengers to another airline. $59,000 will be applied to the T-45 data in this example. The airline utilization rate is higher than the average military aircraft. Using a 4.0 utilization rate, (less than half of the airline utilization figure of 8.7 hours per day) the loss per hour down is $14,750 ($59,000/4.0). The loss per hour ($14,750) multiplied by the number of hours down for unscheduled maintenance in the year (8443.4) equates to a total loss per year of $124,540,150. Using SWR could reduce the loss to $36,116,850 ($14,750 x 2,448.6), a difference of $88,423,300. The loss for the Navy is obviously not revenue but opportunity cost of having the aircraft more available for use. What is demonstrated above is this opportunity cost with a dollar figure applied to it.

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[24] Herndon, Tim, Delta Airlines. e-mail to the author, 28 August 2000.

The unit cost for an SWR unit is $5,500. The total buy-in amount for just the SWR units to the entire 4,050 aircraft currently in the fleet and pipeline at one per every five aircraft is $4.5 million. The number to buy per aircraft or squadron may depend on the deployment and detachment policies of each community. For example, a squadron that keeps most of its aircraft together or in limited detachment modes may only need two or three SWR's, but a detachment-intense unit such as a helicopter squadron may require more units.

SWR provides a powerful tool to combat aging wiring. Studies are also being conducted to combine SWR with NAVAIR tool databases to affect even the repair segment of the fault prosecution timeline, by informing the technician what tools to use to fix the fault.

It is not intended to imply the time saved with SWR translates into manpower reductions for the fleet. Given the nature of aging systems; expanding mission areas; reduced assets; weak retention and recruitment; and the constant reduction of "fair share" manning compared to Billets Authorized (BA) per squadron, adequate manning levels are absolutely necessary. SWR provides the front-line technician to work smarter, not harder. This concept and many others are being supported through programs like the Chief of Naval Operation's (N88) "Smart Squadron" program.

C. PROGNOSTIC HEALTH MANAGEMENT

As mentioned before, the DOD's current cutting edge aircraft in the testing stage is the Joint Strike Fighter and PHM for wiring wasn't considered mature enough for its autonomous logistics system. If true PHM is not available for new production aircraft it cannot be realistically considered for legacy systems at this time. PHM should still be researched as a viable option for future production aircraft.

D. SMART WIRE

Smart Wire is as close to true PHM as we can get. However, implementing Smart Wire into existing platforms basically means re-wiring the aircraft. Therefore, the implementation of Smart Wire would be very costly, intrusive, time consuming and difficult to install. The intrusive nature of installation alone could cause other problems. Only a partial installation of Smart Wire could also be a poor decision if interoperability difficulties and logistical concerns are not addressed. Once again, Smart Wire may be best for future production aircraft.

E. ARC FAULT CIRCUIT BREAKER

Arc Fault Circuit Breaker (AFCB) can be a powerful deterrent to improve safety. Once miniaturized, the installation of AFCB should be much easier than that of Smart Wire. However, AFCB deals with power wires only, which comprise roughly 20% of all wiring.[25] This wiring does present the greatest danger though.

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[25] Sean A. Field, Naval Air Systems Command. e-mail to the author, 17 November 2000.

V. CONCLUSIONS AND RECOMMENDATIONS

A. INTRODUCTION

Aging aircraft wiring presents a dangerous and complicated problem for Naval Aviation. Aircraft are being utilized long beyond their intended life and as each year passes, more complications due to aging become apparent. The aging problem will not go away as new aircraft are few and far between.

Aviation technicians and maintenance decision-makers need the correct tools and practices to combat the aging wire dilemma. This thesis presents some possible options for addressing the aging wire problem.

B. CONCLUSIONS AND RECOMMENDATIONS

1. Arc Fault Circuit Breakers (AFCB) and Standing Wave Reflectometers (SWR) provide the most viable options for investment at this time.

AFCB would be less intrusive to install than Smart Wire and addresses a key safety concern of arcing in aircraft power distribution systems. Standing Wave Reflectometers (SWR) represent a leap forward in being able to prosecute wiring faults in a faster and more effective manner. SWR technology is expandable and relatively inexpensive at $5,500 each. Current troubleshooting methods utilizing human senses, flashlights, and voltmeters are not enough to combat the aging wiring problem. Prosecution of wiring faults can take anywhere from hours to days. Wiring fault prosecution can be reduced to minutes with SWR. SWRs put the right tool in the right hands: the flight-line maintainer. Hard faults can be detected and localized with precise accuracy with SWR. For legacy systems, AFCB and SWR are the answer. As a matter of fact, one major airline has recently ordered SWR units to help maintain their fleet of aircraft.

2. Smart Wire and PHM are not the complete answer at this time for legacy systems.

PHM and Smart Wire are great concepts. However, they consist of re-wiring an aircraft. Given the amount of wiring in modern aircraft and fiscal constraints, this installation would be highly intrusive, labor intensive, time consuming and costly. However, given the thorough nature of major depot maintenance and efforts such as Service Life Extension Programs, perhaps Smart Wire and future PHM technology could be inserted in recognized problem areas. The cost effectiveness of this insertion should be studied and coupled with Reliability Centered Maintenance and trend analysis. The requisite logistical ramifications should also be studied such as interoperability demands, training and supply support.

3. Establishing time limits for aircraft is a must.

At some point it needs to be decided that the Band-Aid type efforts such as modification, refurbishment and SLEPs can be more trouble than a new platform. The cost ramifications of aging systems are just recently being understood. New and current aircraft must have an established time limit for termination. This time limit could be modified by periodic reviews of the aircraft's condition as it ages. This hard limit could also act as an indicator for replacement planning.

4. Training to deal with aging systems is paramount.

Correct training in regards to wire inspections, troubleshooting, repair and the fragile nature of wiring and upkeep is an absolute must. Today's flight line and intermediate level technicians are younger, but more technologically savvy and they must be properly trained and provided the correct tools. Given today's operational tempos and multiple demands, training is often put on the back burner. This trend has to stop.

5. An accurate wire discrepancy data collection system needs to be established.

This can be accomplished with a distinct traceable sub-classification code, which could assist in trend analysis and hazard identification. Appropriate training should be also initiated to properly instruct personnel on how and when to use this sub-classification code.

6. Recent efforts by multiple government agencies, departments, industries and academia in regards to aging systems are beneficial.

The aging problem will only get worse, as fewer costly new systems come on line. Joint efforts provide the pooling of ideas, resources and clout. This coordinated effort to maintain aging systems must continue.

C. FINAL REMARKS

The contributions of this thesis to NAVAIR's pursuit of a solution to deal with aging aircraft wiring are:

-An overview of the aging aircraft wiring problem

-Presentation of emerging technologies such as PHM, Smart Wire, AFCB and SWR.

-A presentation of possible cost savings of emerging diagnostic technology using simple models in areas which are very difficult for the Navy to express, specifically, labor savings in terms of time and dollars, and ramifications of unavailable aircraft in dollars.

-A collection of information, resources and references that act as an enabler to bring analysts, decision-makers and information from various departments and agencies together that may not have been known to each other previously.

APPENDIX A. T-45 WIRE DEGRADERS 01JUN99 – 30JUN00

WUC	NOMENCLATURE	TOTAL NMC	NMCMU
428A6	FUEL QUANTITY INDICATION ACFT WIRING	3355.8	2761
42823	NOSE WHEEL STEERING ACFT WIRING	1821.7	1380.2
4287C	DC GENERATION/CONTROL ACFT WIRING	1330.2	812.8
428K1	RADAR ALTIMETER ACFT WIRING	1100.4	217.6
428C3	CAUTION WARNING SYS (CWS)	755.6	755.6
428H1	IFF SYSTEM ACFT WIRING	749.1	5.1
42833	YAW DAMPER ACFT WIRING	531.3	512.5
42827	WEIGHT ON WHEELS (WOW) ACFT WIRING	529.9	353.6
42884	HYD PRESSURE INDICATION ACFT WIRING	371.4	371.4
428A0	FUEL SYS	281.7	271.4
428E2	ANGLE OF ATTACK (AOA) ACFT WIRING	155.3	155.3
428J1	TACAN ACFT WIRING	148.7	148.7
428G0	INTERPHONE SYSTEM	136.7	136.7
42851	ENGINE CONTROL/INDICATION ACFT WIRING	80.1	80.1
42821	LDG GEAR EXT/RETRACTION ACFT WIRING	58.7	58.7
428A8	FUEL FLOW INDICATION ACFT WIRING	50.6	29.1
42826	LDG GEAR POSN INDICATION ACFT WIRING	41.5	41.5
4283L	SPEED BRAKE CONTROL ACFT WIRING	44.8	44.8
42822	ANTI-SKID SYSTEM ACFT WIRING	34.2	34.2
428F2	UHF/VHF #1, #2 ACFT WIRING	25.8	25.8
4287D	DC POWER DISTRIBUTION ACFT WIRING	28.3	28.3
42850	POWERPLANT INSTALLATION SYSTEM	27.3	27.3
4287E	5 VDC INTERIOR LIGHTING ACFT WIRING	22.1	22.1
428A4	FUEL SYS DISTR/CONTROL ACFT WIRING	18	18
4287A	AC GENERATION/CONTROL ACFT WIRING	17.2	17.2
428A7	FUEL PRESS IND/LL WARNING ACFT WIRING	15.5	15.5
428R1	FWD & AFT EJECTION SEAT ACFT WIRING	15.2	15.2
4283H	FLAT/SLAT CONT & STBY CONT ACFT WIRING	13.5	12
42861	CABIN PRESSURE CONTROL ACFT WIRING	11.1	11.1
428C2	JET PIPE OVERHEAT DETECTION ACFT WIRING	9.5	9.5
428G2	COMMUNICATION/NAVIGATION XFR ACFT WIRING	8.2	8.2
428E3	AIRBORNE DATA RCVR AYA (ADRS) ACFT WIRING	7.8	7.8
42833	SPEED BRAKE POSN INDICATION ACFT WIRING	7.4	7.4
42852	ENGINE STARTING ACFT WIRING	7.4	7.4
428K0	RADAR NAVIGATION SYSTEM	5.6	5.6
428B1	ON BOARD OXYGEN SYSTEM ACFT WIRING	5.1	5.1
4283E	STAB TRIM CONT/STBY CONT ACFT WIRING	4.9	4.9
4283C	RUDDER TRIM CONTROL ACFT WIRING	3.4	3.4
42825	ARRESTING GEAR ACFT WIRING	3.3	3.3
42829	NOC	2.4	2.4
428F0	UHF/VHF COMMUNICATION SYSTEM	2	2
4283G	STAB TRIM POSN INDICATION ACFT WIRING	1.8	1.8
42824	LAUNCH BAR ACFT WIRING	1.6	1.6
42883	HYD FAILURE WARNING ACFT WIRING	1.5	1.5

428EA	MUX BUS (1553B) SYS ACFT WIRING	1.5	1.5
428J0	RADIO NAVIGATION SYSEM	1.4	1.4
42863	CABIN PRESSURE WARNING ACFT WIRING	1	1
4283K	FLAP POSITION INDICATION ACFT WIRING	1	1
428D0	INSTRUMENTATION SYSTEM	0.9	0.9
4287N	28 VDC FLOOD LIGHTING ACFT WIRING	0.9	0.9
428E1	STD ATTD HDG/REF SYS (SAHRS) ACFT WIRING	0.7	0.7
4287B	AC POWER DISTRIBUTION ACFT WIRING	0.6	0.6
428D5	PITOT STATIC &AOA HEAT ACFT WIRING	0.5	0.5
428E0	FLIGHT REFERENCE SYSTEM	0.2	0.2
	TOTAL HOURS	**11852.3**	**8443.4**
	NMC data from 515 report dated 13 SEP 2000		
	Verified by updated 515 report dated 09 NOV 2000		

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APPENDIX B. F/A-18 WIRE DEGRADERS DECEMBER '98-MAY '00

Nomenclature	DMMH	NMCM	NMCS	PMCM	PMCS
NOC	73	0	0	0	0
[WUC NOMENCLATURE NOT FOUND]	85	0	0	0	0
LOWER LEG GARTER	10	12	0	0	0
EQUIPMENT BAY ACCESS COVER NO. 124	82	1	0	0	0
CANOPY RELEASE ASSEMBLY	22	38	146	0	0
R2236/ALQ165 COUNTERMEASURES RCVR	83	0	0	20	130
NOC	25	0	0	0	0
YELLOW ELECTRICAL CABLE W5	33	3,546	926	0	0
AN/ASD10(V) ADVANCED TAC AIR RECON S	82	0	0	0	0
[WUC NOMENCLATURE NOT FOUND]	81	2,824	99	0	0
[WUC NOMENCLATURE NOT FOUND]	0	0	0	0	0
SPECIAL CABLE ASSEMBLY W60211	77	5	2	159	5,649
WARM AIR TEMPERATURE CONTROL VALVE	67	350	109	0	0
[WUC NOMENCLATURE NOT FOUND]	73	7	0	0	0
MX11598/AAS46 AFT SECTION POD	61	802	56	22	29
COMPRESSOR VG CONTROL ACTUATOR ASSY	53	874	145	0	0
NOC	78	31	2	0	0
[WUC NOMENCLATURE NOT FOUND]	78	0	0	0	0
[WUC NOMENCLATURE NOT FOUND]	38	4,479	817	0	0
NOC	67	1	0	0	0
FUEL DUMP CONTROL ASSEMBLY	80	28	2	0	0
SMS CABLE ASSEMBLY W53032	64	0	0	0	0
NAVAIR DWG 841AS425-1395 SMDC (MU69)	79	6	0	0	0
T1599/AST8 AIR DATA PRESS TRANSMITTE	82	1,001	905	0	0
[WUC NOMENCLATURE NOT FOUND]	23	2,295	0	0	0
Y679.850 OUTBOARD FAIRING	45	2	0	0	0
[WUC NOMENCLATURE NOT FOUND]	113	0	0	0	0
FLIGHT CONTROL CABLE ASSY W53303	79	157	11	0	0
NOC	49	5	0	0	0
SHROUD	41	153	105	0	0
SMS CABLE ASSEMBLY W53037	70	0	0	21	136
NOC	23	20	0	0	0
ACFT FIRE DETECTION WRN SYS CONT UNI	37	27	0	0	0
NOC	29	457	0	0	0
FLT CONT SPECIAL CABLE ASSY W60206	77	45	0	0	0
ELECTRICAL CABLE ASSEMBLY W55219	69	17	6	0	0
LOW PRESSURE TURBINE MODULE	110	0	0	0	0
F/A-18E & F ACFT MTD ACCESS DRIVE SY	76	774	0	0	0
CP2414/A DIGITAL MAP COMPUTER	76	73	0	55	0
HORIZ STAB SPINDLE ACCESS COVER NO.	77	0	0	0	0
[WUC NOMENCLATURE NOT FOUND]	70	3	0	0	0
CENTER FUSELAGE WIRING SYSTEM	56	728	0	3	1,164
[WUC NOMENCLATURE NOT FOUND]	28	0	0	0	0
[WUC NOMENCLATURE NOT FOUND]	60	48	12	0	0

NAVAIR DWG 841AS425-1391 SMDC (MU68)	75	4	0	0	0
AS3492/AST4(V) ANTENNA	37	0	0	745	1
[WUC NOMENCLATURE NOT FOUND]	32	0	0	710	0
R2237/ALQ165 COUNTERMEASURES RCVR	74	4	0	171	342
ACFT FIXED LANDING LIGHT	38	3	614	4	72
CABLE ASSEMBLY W52203	60	0	0	27	3
[WUC NOMENCLATURE NOT FOUND]	0	0	0	0	0
AFTERBURNER MODULE	87	6	0	0	0
HARNESS ASSEMBLY	27	0	0	0	0
OIL COOLER	65	27	184	0	0
WINDSHIELD INSTALLATION	68	1,466	0	0	0
[WUC NOMENCLATURE NOT FOUND]	17	2	0	0	0
NOC	39	26	152	0	0
NOC	59	7	0	0	0
[WUC NOMENCLATURE NOT FOUND]	72	0	0	0	0
FLIGHT CONTROL CABLE ASSY W53302	71	530	7	0	0
MECHANICAL INSTALLATION	53	4,243	1,032	0	0
CARTRIDGE-ACTUATED DEVICE (CONTD)	70	8,188	0	0	0
WAVEGUIDE FLUID PRESS REGULATING VAL	28	209	1,551	0	0
CU2264/A MID/LOW BAND COUPLER	11	0	0	0	0
PRIMARY VARIABLE EXHAUST NOZ FLAP	24	10	23	0	0
[WUC NOMENCLATURE NOT FOUND]	96	160	0	124	0
INFLIGHT REFUELING SYSTEM	15	9	521	0	0
NOC	68	867	121	0	0
[WUC NOMENCLATURE NOT FOUND]	12	0	0	0	0
SHUTOFF VALVE	35	312	2	0	0
BACK PLATE ASSEMBLY	30	4	0	0	0
[WUC NOMENCLATURE NOT FOUND]	6	0	0	7	0
HARPOON CABLE ASSEMBLY W56236	4	0	0	0	0
PORT GENERATOR CONTROL UNIT	73	798	506	0	0
NOC	24	3,591	2,371	0	0
EXTERNAL TANK LIQUID QUANTITY XMTR	33	682	197	0	0
CABLE ASSEMBLY W50303	59	405	263	0	0
[WUC NOMENCLATURE NOT FOUND]	84	6	0	0	0
AS3493/AST4(V) ANTENNA	19	6	0	925	207
ARRESTING HOOK ACTUATING CYL ASSY	60	1,466	2,952	0	0
NOC	68	3	0	123	0
NAVAIR DWG 841AS425-1403 SMDC (MU72)	67	6	0	0	0
LOWER FUEL-COMBUSTOR MANIFOLD	13	2	0	0	0
NOC	36	1,609	127	0	0
NAVAIR DWG 841AS425-1113 SMDC (MG88)	68	0	0	0	0
NOC	4	0	0	0	0
[WUC NOMENCLATURE NOT FOUND]	69	0	0	3,201	268
330 GAL EXTERNAL FUEL SYSTEM	66	1	0	0	0
FWD UPR INLET DUCT (BETW Y453 & Y524	67	0	0	0	0

CCU72/A UNLATCH THRUSTER CRTG (XW58)	66	12,261	0	0	[illegible]
NOC	53	0	0	0	[illegible]
RESERVOIR HYDRAULIC FLUID MANIFOLD	50	3,986	49	0	[illegible]
ELECTRIAL EQUIPMENT RACK (ALQ165)	66	0	0	0	[illegible]
NOC	55	720	0	0	[illegible]
LOW PRESSURE TURBINE NOZZLE AIR SEAL	69	0	0	0	[illegible]
NOC	65	3	3	0	[illegible]
NOC	50	0	0	0	[illegible]
NAVAIR DWG 841AS425-1397 SMDC (MU70)	65	4	0	[illegible]	[illegible]
DATA LINK CABLE ASSEMBLY W50102	64	983	5	[illegible]	[illegible]
AN/DPT1 RADAR TRANSMITTING SET	65	0	0	[illegible]	[illegible]
NOC	60	15	0	887	0
CABLE ASSEMBLY W60222	52	0	0	0	[illegible]
NOC	50	159	179	0	0
AIRCRAFT-MISSILE FAIRING NO. 120	65	15	0	0	0
SPECIAL CABLE ASSEMBLY W60212	58	0	0	8	0
[WUC NOMENCLATURE NOT FOUND]	72	1	3	0	0
NOC	46	3	66	0	0
AFT FUSELAGE (CONTD)	54	537	95	0	0
NAVAIR DWG 841AS425-1109 SMDC (MG86)	65	1	0	0	0
COMPRESSOR INLET PRESSURE SENSOR	8	2,226	5,004	0	0
[WUC NOMENCLATURE NOT FOUND]	0	0	0	0	0
SPECIAL CABLE ASSEMBLY W60232	61	136	2	3	0
FLIGHT CONTROL CABLE ASSY W60250	63	16	0	0	0
[WUC NOMENCLATURE NOT FOUND]	58	40	29	0	0
ENVIROMENTAL CONT CABLE ASSY W61222	59	221	745	0	0
NOC	20	0	0	0	[illegible]
[WUC NOMENCLATURE NOT FOUND]	3	0	0	0	0
OUTBOARD LEADING EDGE FLAP	62	745	2,762	0	0
NAVAIR DWG 841AS425-1119 SMDC (MG91)	64	0	0	0	0
AS4358/A ANTENNA	69	298	135	1	0
RUDDER SYSTEM	62	50	0	0	0
STANDBY INSTRUMENT CABLE ASSY W50323	60	0	0	142	0
AIRCRAFT INTERFACE UNIT F-18	62	0	0	20	762
OH59(V)/AST4(V) POD GP SIM SET	57	0	0	0	0
SHORT MAIN AFTERBURNER SPRAYBAR	61	32	0	0	0
[WUC NOMENCLATURE NOT FOUND]	88	0	0	0	0
NOC	35	96	0	0	0
TE FLAP ACTUATOR ACCESS COVER NO. 78	54	783	769	0	0
CD62/ALR67(V) DISTRIBUTION CONTROL	31	0	0	0	0
AVIONICS EMERGENCY RAM AIR SCOOP	55	432	0	0	0
NAVAIR DWG 850AS875-135 (SP19)	62	0	0	0	0
[WUC NOMENCLATURE NOT FOUND]	67	1	0	0	0
FORWARD FUSELAGE SECTION	61	364	0	0	[illegible]
AUXILARY SCOOP	49	0	0	169	509

NAVAIR DWG 841AS425-1117 SMDC (MG90)	62	0	0	0	0
GRAY ELECTRICAL CABLE W3	25	95	193	0	0
NLG DOOR UPLOCK HOOK	43	184	71	0	0
AS4440/APX111(V) ANTENNA	19	0	0	1	0
CABLE ASSEMBLY W53214	59	0	0	0	0
NOC	27	0	0	0	0
DIVERTER VALVE PUSH-PULL CONTROL ASS	36	0	0	0	0
[WUC NOMENCLATURE NOT FOUND]	9	0	0	2	0
A/P22P-16 AIRCREW PROTECTIVE ASSEMBL	14	0	0	0	0
[WUC NOMENCLATURE NOT FOUND]	0	0	0	0	0
[WUC NOMENCLATURE NOT FOUND]	0	0	0	0	0
[WUC NOMENCLATURE NOT FOUND]	59	0	0	0	0
UNIVERSAL JOINT	60	8,120	86	0	0
NOC	58	0	0	0	0
NAVAIR DWG 850AS875-107 (SP05)	59	0	0	0	0
NOC	12	1	0	0	0
[WUC NOMENCLATURE NOT FOUND]	33	0	0	0	0
ARRESTING HOOK STRL CMPNT PYLON SPRT	43	0	0	0	0
NOC	33	27	117	0	0
COMMUNICATION CABLE ASSEMBLY W52006	58	20	8	0	0
ACCESS COVER NO. 107	42	0	0	0	0
AFTERBURNER LINER	78	0	0	0	0
AN/ASW44 SYSTEM AIRCRAFT WIRING	55	122	176	0	0
AFT FUSELAGE (CONTD)	49	0	0	0	0
EMER BRAKE/LDG GR COUPLER ASSEMBLY	32	2,317	0	0	0
SMS CABLE ASSEMBLY W50210	13	0	0	4	73
ARRESTING HOOK CABLE ASSY W61220	29	17	0	0	0
F/A-18E & F PWR PLANT CONTROL SYSTEM	56	23	0	0	0
RH CONSOLE	39	0	0	0	0
NOC	42	3	10	0	0
GUN GAS PURGE DR LIN ACTG CYL ASSY	31	21	0	0	20
EXTERIOR LIGHTING	54	0	0	0	0
ELECTRICAL CABLE ASSEMBLY W55218	59	60	1	0	0
[WUC NOMENCLATURE NOT FOUND]	67	0	0	0	0
MISCELLANEOUS WIRING SYSTEMS	59	0	0	62	0
[WUC NOMENCLATURE NOT FOUND]	4	0	0	0	0
MX11627/AST6(V) ELEK CMPNT SHLD POD	53	22	20	0	0
ELECTRIC CABLE ASSEMBLY W60034	36	0	0	7	1,311
OUTBD LEF LOWER FAIRING NO. 476	53	609	0	0	0
TOTAL	8,771	79,222	24,502	9,569	10,708

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APPENDIX C. EA-6B WIRE DEGRADERS DECEMBER '98-MAY '00

WUC	Nomenclature	DMMH	NMCM	NMCS	PMCM	
42800	HYDRAULIC TUBING/HOSE	641	2,563	105	0	
42820	NLG HYDRAULIC COMPONENTS	621	5,531	2,081	0	
42829	[WUC NOMENCLATURE NOT FOUND]	331	2	4	898	
42830	EXTENSIBLE EQPT PLATFORM SYSTEM	618	3,282	697	9	
42831	NOC	511	2,067	568	0	
42832	C7949( )/ARA63( ) RECEIVER CONTROL	483	0	0	2,794	9
42839	CPK113/A37J2 POWER TRIM COMPUTER	422	0	0	0	
42840	AOA/STALL WARNING SYSTEM	564	213	285	96	
42843	WING TIP	619	0	0	1	10
42844	[WUC NOMENCLATURE NOT FOUND]	272	0	0	0	0
42845	KEEL F.S. 293 TO 368	472	478	650	0	0
42846	TURN/SLIP/BANK INDICATOR	141	24	10	143	73
42847	POWER CONTROL RELAY BOX	343	2,585	2,354	2,482	1,593
42848	FLIGHT HYDRAULIC POWER SYSTEM	549	564	1,020	0	0
42849	SPEED BRAKE POSITION TRANSMITTER	634	832	168	302	17
42850	CV2702/A A TO D CONVERTER	150	4,764	442	5	55
42851	MX3162/ASW16 AIRCRAFT CONTROL STICK	502	2,753	1,076	7	599
42852	ARRESTING HOOK DASHPOT	562	6,485	1,178	0	0
42858	NOC	314	692	375	0	0
42859	FLAP CONTROL OFFSET GEARBOX	163	766	308	0	0
42860	MLG DOWN AND LOCK SWITCHES	549	2,261	228	0	0
42861	[WUC NOMENCLATURE NOT FOUND]	17	2	5	0	0
42862	IFF ANTENNA	267	18	39	374	1,589
42865	COCKPIT EQUIPMENT	499	125	0	0	0
42866	ID2121( )/ARC FREQUENCY CHANNEL IND	492	947	3	826	296
42867	IFF/SIF SYSTEMS AIRCRAFT WIRING	480	175	157	291	211
42868	EQUIPMENT COOLING VALVE	336	915	307	2	7
42869	VHF COMMUNICATIONS SYS ACFT WIRING	579	0	0	3,204	268
42870	RUDDER CONTROL HYDRAULIC	549	1,667	739	0	0
42872	CANOPY JETTISON VALVE	400	534	191	0	0
42873	LIFT/SPEED CONTROL SURFACES	373	560	3	0	0
42874	RADAR NAVIGATION SYS ACFT WIRING	572	41	0	718	23
42877	NOC	270	1,455	0	4,930	586
42879	MT6126/ALQ99F(V) ELECTRICAL EQPT RAC	558	137	0	866	18
42880	BULKHEAD	427	713	6	0	0
42884	RATE SWITCHING GYROSCOPE	191	2,714	142	33	12
42885	C9871/ARC RADIO SET CONTROL 313N-5	595	116	638	2,051	4,869
42886	AIR COND/PRESSURIZATION/ICE CONTROL	372	644	20	0	0
42887	NOC	207	1,052	1,718	0	0
42888	SA2157/ARC SWITCHING UNIT	156	310	0	8	82
42889	NOC	534	3,056	188	0	0
42890	[WUC NOMENCLATURE NOT FOUND]	5	0	0	0	0
42899	R1844/ALQ99( )(V) CM RECEIVER	68	0	0	3	0
428--	TSEC/KY58 SIDE MOUNT ADAPTER	69	4	0	80	128

4282-	STEERING HYDRAULIC COMPONENTS	50	0	0	8	2
4282K	NOC	57	0	0	0	0
4282L	ARRESTING HOOK POSITION SWITCH	59	0	0	27	0
4284-	NOC	54	0	0	6	0
4284A	AN/ALQ99( )(V) CM SET OR41( )	57	0	0	0	0
4284S	VERTICAL STABILIZER FAIRING	59	0	0	31	0
4284T	TYPE KJ4 CMPS TRANSMITTER	40	0	2	26	0
4284U	ROCKET FIRING UNIT	44	0	0	203	54
4284V	OXYGEN PANEL	29	0	0	0	0
4284W	NOC	51	0	0	7	0
4284X	FUSELAGE MATING FITTING	58	0	0	312	0
4284Y	ANTI ICE VALVE	57	0	0	161	0
4284Z	WING FOLD SEAL	57	0	0	2	174
4285-	WINGFOLD HYDRAULIC	57	0	0	245	0
4285A	SLAT CONTROL SWITCH	56	0	0	13	0
4285B	FILTER MODULE	57	0	0	22	0
4285L	WINGFOLD ELECTRICAL	55	0	0	0	0
4285M	EXT POWER RECEPTACLE LIGHT	55	0	0	1	0
4285N	[WUC NOMENCLATURE NOT FOUND]	57	0	0	142	0
4286-	NOSE WHEEL WELL CURTAIN INSTALLATION	55	0	0	1,465	0
4287A	LANDING GEAR CONTROL MECHANICAL	55	0	0	69	71
4287B	NOC	57	1	0	731	1
4287C	POWER BRAKE VALVE	40	0	1	44	0
4287D	ABU4( )/A ACCELEROMETER	2	0	0	0	0
4287E	DIRECTIONAL CONTROL SYSTEM	0	0	0	0	0
4288A	NOC	37	0	2	22	0
4289B	PRESS R BLEED CONT SPRT ASSY(P6/8/40	29	0	1	11	22
4289C	NOC	51	0	2	0	0
4289D	DHK8/A24J-25(V) FUEL TANK SENSING UN	26	0	0	0	0
428A1	NOC	74	0	0	6,340	144
428A9	PERSONNEL EQUIPMENT	54	0	0	440	0
	TOTAL	18,966	51,048	15,713	30,451	12,158

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APPENDIX D. ACRONYMS

1. A/C - AIRCRAFT
2. AFCB – ARC FAULT CIRCUIT BREAKER
3. ASTF – AGING SYSTEMS TASK FORCE
4. AVDLR – AVIATION DEPOT LEVEL REPAIRABLE
5. AWIGG – AIRCRAFT WIRING & INERT GAS GENERATOR
6. BA – BILLETS AUTHORIZED
7. BIT – BUILT IN TEST
8. BuNo – BUREAU NUMBER
9. CBM – CONDITION BASED MAINTENANCE
10. CNO – CHIEF OF NAVAL OPERATIONS
11. DARPA – DEFENSE ADVANCED RESEARCH PROJECTS AGENCY
12. DOD – DEPARTMENT OF DEFENSE
13. FAA – FEDERAL AVIATION ADMINISTRATION
14. FY – FISCAL YEAR
15. IPT – INTEGRATED PROCESS TEAM
16. JDIS – JOINT DISTRIBUTED INFORMATION SYSTEM
17. JSF – JOINT STRIKE FIGHTER
18. LRU – LINE REPLACEABLE UNIT
19. MEOS – MICRO ELECTRO-OPTICAL SYSTEM
20. MEMS – MICRO ELECTRO-MECHANICAL SYSTEM
21. MMH – MAINTENANCE MAN HOURS
22. NASA – NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
23. NAVAIR – NAVAL AIR SYSTEMS COMMAND
24. NAVSEA – NAVAL SEA SYSTEMS COMMAND
25. NAVWAG – NAVAL AIR VEHICLE WIRING ACTION GROUP
26. NMC – NON-MISSION CAPABLE
27. NMCM – NON-MISSION CAPABLE MAINTENANCE
28. NMCS – NON-MISSION CAPABLE SUPPLY
29. NMCMU – NON-MISSION CAPABLE MAINTENANCE UNSCHEDULED
30. NTSB – NATIONAL TRANSPORTATION & SAFETY BOARD
31. O&M, N – OPERATIONS & MAINTENANCE NAVY
32. ONR – OFFICE OF NAVAL RESEARCH
33. OS & TP – OFFICE OF SCIENCE & TECHNOLOGY POLICY
34. PHM – PROGNOSTIC HEALTH MAINTENANCE
35. PMC – PARTIAL MISSION CAPABLE
36. PMCM – PARTIAL MISSION CAPABLE MAINTENANCE
37. PMCMU – PARTIAL MISSION CAPABLE MAINTENANCE UNSCHEDULED
38. PMCS – PARTIAL MISSION CAPABLE SUPPLY
39. SLEP – SERVICE LIFE EXTENSION PROGRAM
40. SWR – STANDING WAVE REFLECTOMETER

41. TDR – TIME DOMAIN REFLECTOMETRY
42. USAF – UNITED STATES AIR FORCE
43. WSSIWG – WIRE SYSTEM SAFETY INTERAGENCY WORKING GROUP

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APPENDIX E. GLOSSARY

1. **DIAGNOSTICS** – Identification by examination or analysis.
2. **IMPEDANCE** – A measure of the total opposition to current flow in an alternating current circuit.
3. **PROGNOSTICS** – Prediction on the basis of present indications.
4. **SPECTRA** – Plural of spectrum
5. **SPECTROSCOPE** – Any of various instruments for resolving and observing or recording spectra.
6. **SPECTRUM** – The distribution of a characteristic of a physical system or phenomenon, especially the distribution of energy emitted by a radiant source arranged in order of wavelengths.
7. **STANDING WAVE REFLECTOMETER** – A non-intrusive impedance-based cable tester.

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